N94-23863

ULYSSES LOG 1992

Raúl García Pérez
D. Spacecraft Operations Manager

European Space Agency (ESA), European Space Operations Centre (ESOC), Darmstadt, Germany
Currently working at the Jet Propulsion Laboratory (JPL), Pasadena, USA

ABSTRACT

The Ulysses Log tells the story of some intriguing problems that *we (=The Spacecraft Team)* have encountered. Ulysses was launched on 6 Oct 1990 and made the fastest trip to Jupiter (8 Feb 1992). As it is going out of the ecliptic, let us review some of the Ulysses Log Entries.

Summary:

1. INGENIOUS MANOEUVRES
    1.1 The Nutation Anomaly
    1.2 Escape from Direct Sun Pointing
2. TELECOMMUNICATION PROBLEMS
    2.1 Telecommand sensitivity
    2.2 Solar Interferences
3. SURPRISES
    3.1 Spontaneous Reconfigurations
    3.2 Jupiter. Expect the Unexpected
    3.3 A Computer Anomaly (CTU2)

Key Words: Anomaly, Nutation, Jupiter, Conjunction, Doppler, Spontaneous Reconfiguration.

1. INGENIOUS MANOEUVRES

1.1 The Nutation Anomaly

The Sun *unevenly heats* a flexible boom as the Spacecraft rotates. This is enough to cause an important dynamic disturbance.

Ulysses has 3 flexible booms:

- *Two Wire-Booms* that rotate in a plane perpendicular to the Spacecraft Spin Axis. They are located on either side of the Spacecraft Body and their combined length tip to tip is 72.5m (237.86 ft). The centrifugal force of a tip mass keeps them straight.
- *One Axial-Boom* that bends slightly due to the centrifugal force, but remains close to the Spacecraft Spin Axis. Its length tip to root is 8m (26.66 ft).

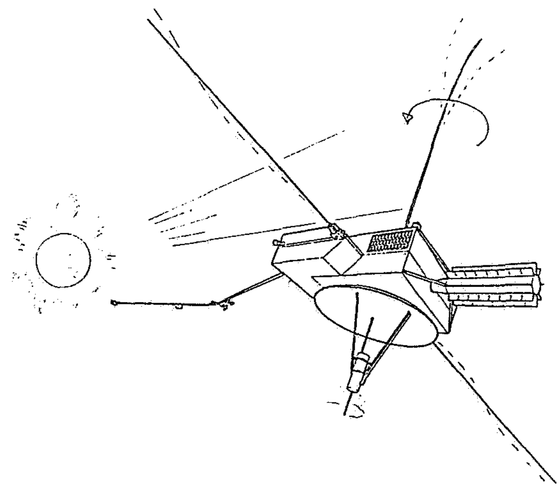


Fig. 1: Ulysses and its flexible elements.

1.1.1 When the Boat Rocks

Deploying a large sail in a strong wind is a delicate operation for a sailing boat. Similarly, deploying the flexible booms in a strong solar wind was a difficult experience for the Ulysses Spacecraft.

The Solar thermal energy caused the axial boom to oscillate. This oscillation excited an undesirable *wobbling* of the Spacecraft body, which is called *Nutation.*

Ulysses Nutation causes the following *effects*:

- *Risk of structural damage.* The axial boom cross section can collapse into a flat tape permitting its storage during the Launch Phase. If the axial boom bends it could wrap around and damage any structure or rip the thermal blankets.
- *Ulysses cannot transmit data to the Earth* because the antenna loses Earth pointing. In the early Mission when Ulysses was closer to the Earth *we* resorted to the S-Band, which permits wider off-pointing. This will not be possible in the future due to the limited range of the S-Band Transmitter.
- *Degrades The Science Data.* Instrument pointing oscillates and significantly degrades the Science Data.
- *Spacecraft functions run unsynchronized.* The Spin Phase Reference is corrupted. This alters the Spacecraft Manoeuvres and degrades further the Science Data.

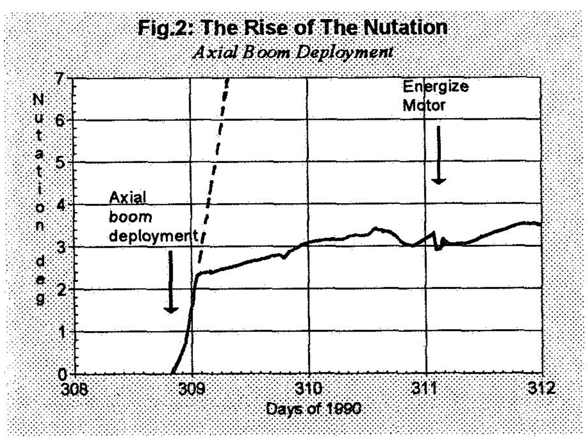


Fig.2: The Rise of The Nutation

The Nutation can be regarded as a small energy imbalance and many normal disturbances would cause it. For this reason any spinning spacecraft would use one of the following two *Methods of Nutation Control*:

- *Passive.* A friction device dissipates the energy of the undesirable motion. Ulysses uses this method.
- *Active.* A well designed manoeuvre precisely corrects the imbalance.

1.1.2 What did *we (=The Spacecraft Team)* try?

The Passive Nutation Dampers were initially flooded by the continuous solar energy input to the system. After 6 long hours of exponential growth The Nutation finally reached an equilibrium at 2.5 degrees full cone (fig. 2).

In the next 4 days the Nutation Amplitude grew up to 4 degrees.

In this early days *we* tried 2 *Active Strategies*:

- *Energize the boom deployment motor* to eliminate any free-play and stiffen the boom root. The Ulysses flexible booms cannot be undeployed because the motors run in a single direction and stall at the end.
- *Execute Nutation Damping Manoeuvres.*

Both had a very limited effect and the Nutation continued to increase up to 6.2 degrees.

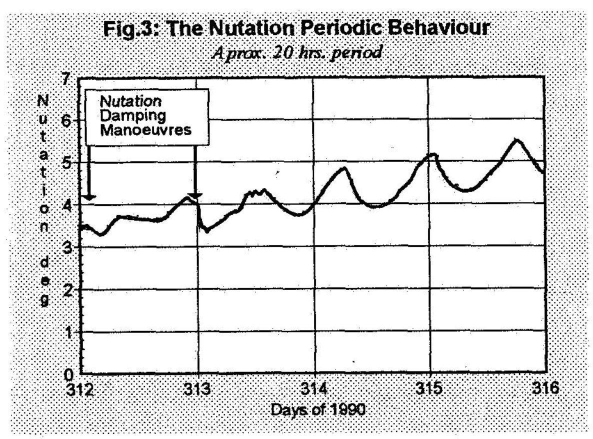


Fig.3: The Nutation Periodic Behaviour

After the Nutation Damping Manoeuvres, the Nutation Amplitude started a *20 hours periodic behaviour* (fig. 3). This was probably a clockwork instability of the equilibrium between the Nutation and the Dampers. As with many other phenomena, this remains unexplained.

The Resonance Phenomena were not dominant in the Ulysses Nutation. The analysis of the resonances of the flexible elements indicated that lowering the spin rate could reduce the Nuta-

tion. But from the rigid body theory alone the Nutation would increase. When finally approved the *spin-down manoeuvre to 4.9 rpm* actually increased the Nutation Amplitude.

A corrective *spin-up manoeuvre to 5 rpm* reduced the Nutation below the original level, but the Nutation regained its original amplitude in 24 hours. In further attempts *we* brought the spin rate up to 5.2 rpm, but the Nutation growth consumed all the initial improvements.

1.1.3 The Solution and the Future of the Nutation

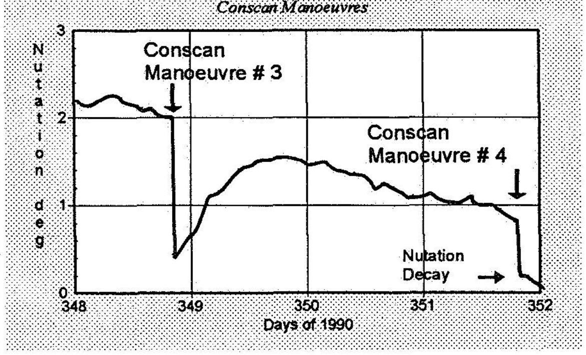
Finally *we (=The Spacecraft Team)* tried the *Conscan Manoeuvre.* This is an Automatic Earth Pointing Manoeuvre which uses the up-link signal as a beacon to track the Earth.

The Conscan Manoeuvre was designed to have some Nutation damping properties and in fact it is very effective in this respect.

The Conscan Manoeuvre rapidly reduced the Nutation to 0.25 full cone (fig, 4), and the success was fully repeatable. To conserve this reduction it is necessary to keep activated the Conscan Manoeuvre, whose fuel consumption is not excessive.

The conditions that produce the Ulysses Nutation *will recur in 1994 and 1995.* This periods contain the *Solar Polar Passes* which constitute our *Prime Mission.* But *we* are confident because the Conscan Manoeuvre is an effective tool to prevent the Ulysses Nutation.

Fig.4: The End of The 1990 Nutation
Conscan Manoeuvres



1.2 Escape from Direct Sun Pointing

The Ulysses Attitude and Orbit Control System (AOCS) has a *blind spot* in the direction of the Sun. It has the shape of a circle with a radius of 1.25 degrees and centered on the Sun.

Ulysses loses its attitude reference when the Spacecraft main axis is pointing within this circle. The spin-syncronous functions go wrong and this includes the thruster firing for the manoeuvres. In principle Ulysses cannot manoeuvre out of the blind spot.

Nominally *we* should avoid falling into this trap. But in case of accident, there were no other means of escape than *waiting until the Sun moves away.*

The challenge for *us (=The Spacecraft Team)* was to *find a quicker alternative* by combining the existing Spacecraft capabilities.

The Conscan Manoeuvre is again part of the solution and the strategy is as follows:

- *Program a clock-work Spin Reference Pulse* to substitute the one that depends on the Sun sensors. The Spacecraft does not know where the Sun is and the phase reference is artificial, but the Spin Period is valid.
- *Activate the Conscan Manoeuvre.* Using the artificial reference The Spacecraft starts tracking the Earth, and the Earth pulls Ulysses out of the blind spot.

In this configuration the Spacecraft gets a totally wrong idea about its inertial attitude. But it is able to manoeuvre precisely towards the Earth. Indirectly, *the Earth provides the missing reference.*

We were close to use this strategy during the second Opposition (Inferior Conjunction). The Sun Avoidance Manoeuvre failed at the edge of the blind spot. But the Sun Reference did not totally fail and *we* were able to come out with a conventional manoeuvre.

2. TELECOMMUNICATION PROBLEMS

2.1 Telecommand Sensitivity

The acquisition bandwidth for the Telecommand Subcarrier is quite narrow (± 1.7 Hz). This lowers the noise in the Telecommand Decoder but demands a very accurate uplink frequencies. *We (Spacecraft Team)* have two problem areas:

- *The DSN Command Processing Assembly* (CPA) provides valid subcarrier frequencies with sufficient resolution. But their accuracy can degrade beyond the Ulysses requirements. Although the CPAs have a command verification loop to sense the discrepancies, its alarm limits cannot be set narrowly enough.
- *The Doppler Effect must be compensated.* The Spacecraft velocity relative to the Earth causes a frequency change (Doppler Effect). This must be periodically corrected by making the opposite change in the Telecommand Subcarrier Frequency and Bit Rate. *The Ulysses injection velocity was the highest ever.* Midway to Jupiter the velocity relative to the Earth reached 41Km/sec and created the maximum Doppler Effect.

2.2 Solar Interferences

During Solar Conjunctions the *Solar Corona* causes radio interference. The phenomenon is well known. But the Spacecraft peculiarities and the changing solar conditions makes it different every time.

In principle the S-Band uplink should have been more affected than the X-Band downlink. But the downlink was in coherent mode and incorporated also the uplink interference. The coherent mode was necessary for the Solar Corona Sounding Experiment.

The Ulysses X-Band Telemetry was quite affected by the Conjunction while the S-Band telecommands were almost unaffected. Only one command failed during the Conjunction Period.

The *Spectral Broadening* of the signal was the predominant phenomenon. The received frequency varies all the time and the carrier spectrum becomes a bell-shape rather than a line (fig. 5).

To fight the Spectral Broadening *we* asked DSN *to widen the Receiver and the Subcarrier Loop Bandwidth.* This technique was used by previous projects and it is a trade-off between Acquisition Threshold and Spectral Broadening.

Another observation was that the *measured Signal to Noise Ratio* (SNR) may not represent the real data degradation. The data quality was sometimes very bad while the SNR was above the theoretical threshold. The author attributes this phenomenon to the fact that the Solar Interference can be *non-white or non-gaussian.*

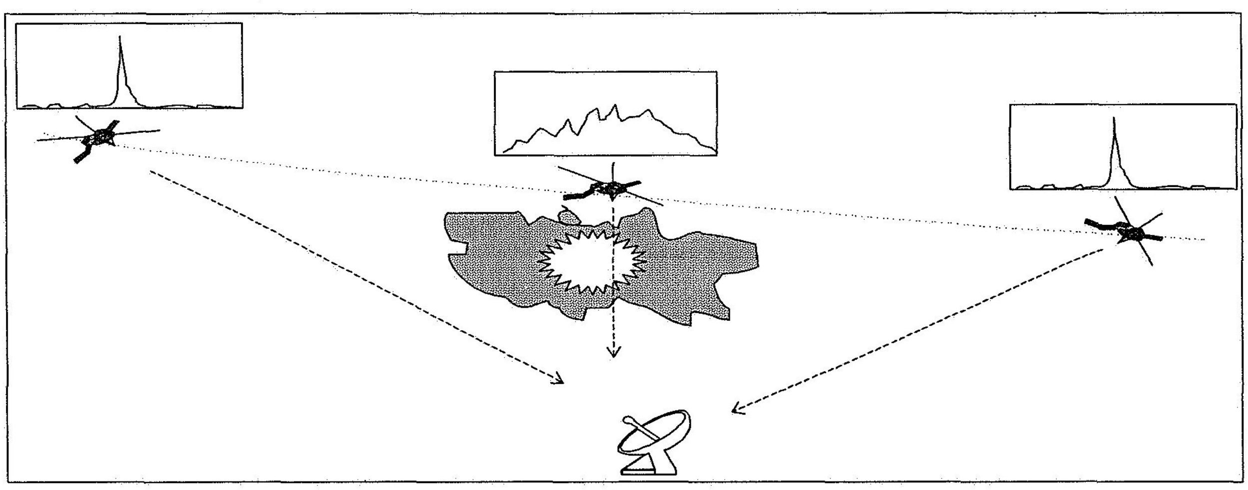


Fig. 5.- Spectral Broadening during Conjunction

3. SURPRISES

3.1 Spontaneous Reconfigurations

Two types of *Spontaneous Reconfiguration* have occurred:

- *TWTA Change-over*: The TWTA (Traveling Wave Tube Amplifier) is the X-Band Transmitter output stage. There are two of them plus a switch-over logic triggered by a power transient on the active tube. The Change-over occurred once, but its cause did not appear in the telemetry.
- *DNEL (Disconnect Non Essential Loads)* is an on-board protection that disconnects all the power consumers not needed for survival.

  DNEL may occur for several reasons related to a power system overload. But it might also occur due to an upset in the logic circuits.

  DNEL happened during a quiet period of the ecliptic mission. One telemetry format was perfect and the next one was evidencing DNEL. Once again the cause for the Spontaneous Reconfiguration did not appear in the telemetry.

A fast transient may have been missed because the regular sampling rate of the engineering parameters is 1 sample/64 secs. Therefore we will never know whether the Spontaneous Reconfigurations were due to a genuine power transient or not. But their occurrence significantly affected the Jupiter Encounter Planning.

3.2 Jupiter. Expect the Unexpected

All four Spacecraft to encounter Jupiter before Ulysses reported anomalies related to the harsh radiation environment. *Some of the effects on Pioneers and Voyagers* were:

- Spurious Command Execution
- Spontaneous Change of State
- Temporary Instrument Saturation
- Permanent Instrument Degradation
- On-board Computer halted frequently
- Spacecraft Clock Corruption
- Oscillator Frequency Shifts

This was an important lesson to learn. Protecting Ulysses against Radiation was a strong requirement during Design and Integration. Even so, *we (=The Spacecraft Team)* prepared procedures for versions of the above that might apply to Ulysses. Many *Contingency Procedures to protect saturated sensors* were applied. Fortunatelly some other Contingencies like the Spontaneous Reconfigurations or the Spacecraft Clock Reset did not occur during Jupiter Encounter.

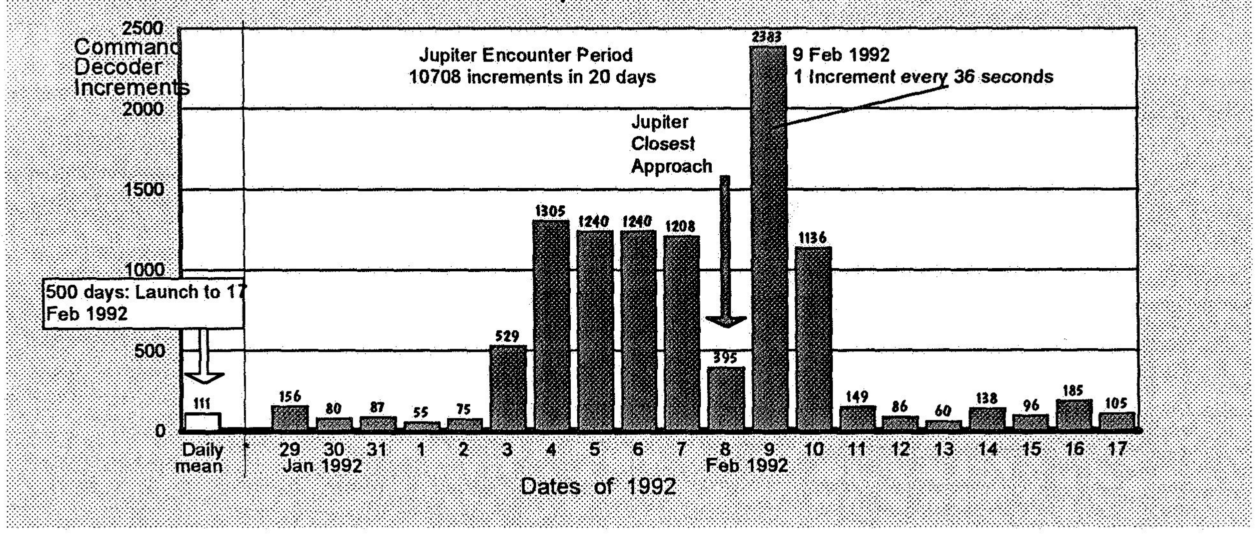
To make possible the Operations Timeline became the real problem for two reasons:

- *The high power demands during Jupiter Encounter* could not be easily accommodated. The RTG (Radio-isotope Thermoelectric Generator) was delivering less power than predicted. The Science Teams agreed upon a *power-sharing timeline*. The Spacecraft Team reduced to the bare minimum the non-science power consumption and all the requirements were successfully met.
- *Command Activities were very Complex* because of the following three requirements:
  - » *Command Rate*: this was so high that Instrument's commanding time conflicted. During Jupiter Encounter *we* sent as many as 20% of all the commands that were sent before (fig. 6).
  - » *Accurate Command Timing*: it was required to within 5 seconds.
  - » *Flexibility*: Many Science Teams wanted to command in near real-time based on their observations.

The intense operations during Jupiter Encounter went like clockwork. *We atribute the success to the highly detailed Timeline, and the good communication with the Science Teams*. The excitement of the Science Teams about the valuable scientific results obtained (Ref. 4) was an excellent pay-off for all the efforts.

Figure 6 : Ulysses Command Activity Peak

Jupiter Encounter



3.3 A Computer Anomaly (CTU2)

The Central Terminal Unit number 2 (CTU2) is a redundant computer, that belongs to the Data Handling System (DHS). Its only purpose is to take over in case of a CTU1 failure.

Ulysses (in flight) has used CTU2 twice:

- *In the Post-Launch Redundancy Check-out* all the CTU2 functions were *normal.*
- *In the Post-Jupiter Redundancy Check-out* the CTU2 Telemetry Generator showed a *minor anomaly.*

Every 16 telemetry bits, two are linked by a shortcircuit (and-wired, in Electronics jargon). This means that the 2 bits behave as follows:

Real Values	Telemetry Values
0 0	0 0
0 1	0 0
1 0	0 0
1 1	1 1

We are modifying the ground systems to cope with this. If *we* ever have to use CTU2, the systems will be able to process telemetry with minimum degradation. But *CTU1 is in perfect shape* and there is no reason to use CTU2.

4. CONCLUSION

We have reviewed in this paper the most interesting Spacecraft Operations Events during the first *two years of the Ulysses mission.*

The Nominal Mission lasts three years more. *The uncharted territory starts really here* : Ulysses is now flying away from the Ecliptic Plane *towards Solar Latitudes never explored before.*

REFERENCES

1. Angold, Nigel, and Hamer, Paul 1992. The Ulysses Spacecraft Monitoring and Control Concepts and Realities. In *Proc. SpaceOps 92*

2. Angold, Nigel. Beech, Peter. García-Pérez, Raúl. McGarry, Andrew. and Standley, Shaun 1992. Ulysses Operations at Jupiter. In *ESA Bulletin No. 72, Nov 1992*

3. Beech, Peter. and Meyer, Donald. Post-Launch Operations . In *ESA Bulletin No. 63 , Aug 1990.*

4. Ulysses at Jupiter. 15 Articles in a Ulysses dedicated issue: *Science vol. 257, 11 Sep 1992*

5. Ulysses Instruments. Dedicated issue: *Astronomy and Astrophysics vol. 92 No.2, Jan 1992.*